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FACULTY OF ENGINEERING AND COMPUTER SCIENCE

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13 May 1993
(Revised 27 October 1994)
Final Report

LOW FREQUENCY ANTENNA COUPLING MODELLING

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1. INTRODUCTION

The Canadian Aircraft-inter-Antenna Propagation with Graphics or **AAPG** computer code forms the core of the EMC prediction software to be used by DND departments and their contractors as a practical tool for the analysis of the interaction of avionics systems. The coupling path algorithms in this code are based on ray optical techniques which calculate geodesic coupling paths on simplified cylinder/cone/plane models of the aircraft or helicopter. The Uniform Theory of Diffraction (UTD) is used to compute the path loss along the geodesic trajectories.

Because of the inherent limitations in the ray-optical approach in AAPG, it is prudent to ask whether the numerical coupling values so derived for lower frequencies, say HF through UHF are still relevant as EMC approximations, and whether other techniques can be used to answer this question. At the same time, these techniques might be used to overcome the inherent shortcomings.

This research contract has been focused on ways to answer the two main questions discussed above. The objectives and specific tasks were defined in the contract Statement of Work or SOW, which is included as Appendix A of this report. This report summarizes the status of results with regard to these objectives and the specific tasks of the SOW. It should be noted that this is the first time that such an investigation has been carried out in Canada in a systematic way.

The initial set of new and interesting results at HF and VHF frequencies is presented below. These computational research explorations used HF wire-grid models of the CP-140/AURORA aircraft. For coupling studies at VHF frequencies, denser wire-grid VHF models of the CL-600/CHALLENGER were developed.

The computations thus divide themselves into **HF/In-Band** and **HF/Out-of-Band** coupling calculations carried out by two different methods, each corresponding to AAPG simulations. These investigations correspond to tasks in paragraphs "a.1 through a.3" and "b.1 through b.4" of the Statement of Work.

2. HF IN-BAND CALCULATIONS

In previous DND-sponsored contract research work several models of the CP-140/AURORA were developed [1]. The two most recent ones are labelled 4GP and AUR7P. They are shown in Figures 2.1 and 2.2 respectively. Model 4GP is intended for runs with excitation of the port HF antenna and consists of 550 segments. It is representative of the latest models in a wire-grid evolution sequence based on minimizing the number of segments while investigating model refinement by means of localized improvements. With the availability of the EMC Laboratory DEC RISC workstations, the number of segments assumed a lesser importance, although cost-efective models continue to be sought. Model AUR7P is a development that is representative of a more modern and elegant model where universal implementation of the EMC Laboratory guidelines is achieved. It consists of 815 segments.

These two models were exploited for the two coupling calculation methods:

- the first being the calculation of the HF near field with the models unchanged and using effective height values of the receive antennas to calculate the coupling, and

- the second being a more direct method that incorporates the passive antenna into the wire-grid models, loads it with open circuit and 50 ohm termination values, and then computes the coupled voltage values.

The latter method was used in the EC-130/TACAMO HF antenna study for the U.S. Navy[2].

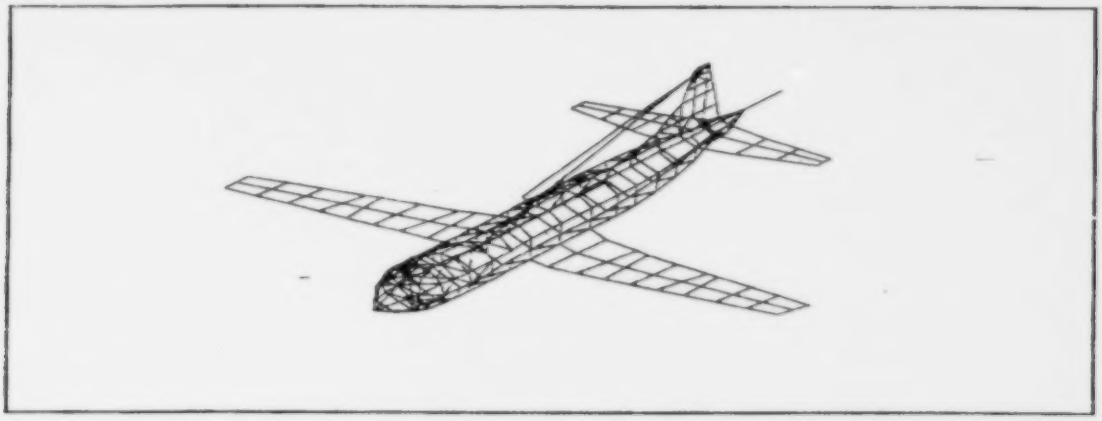

Fig. 2.1 - CP-140/AURORA Model 4GP, 550 Segments

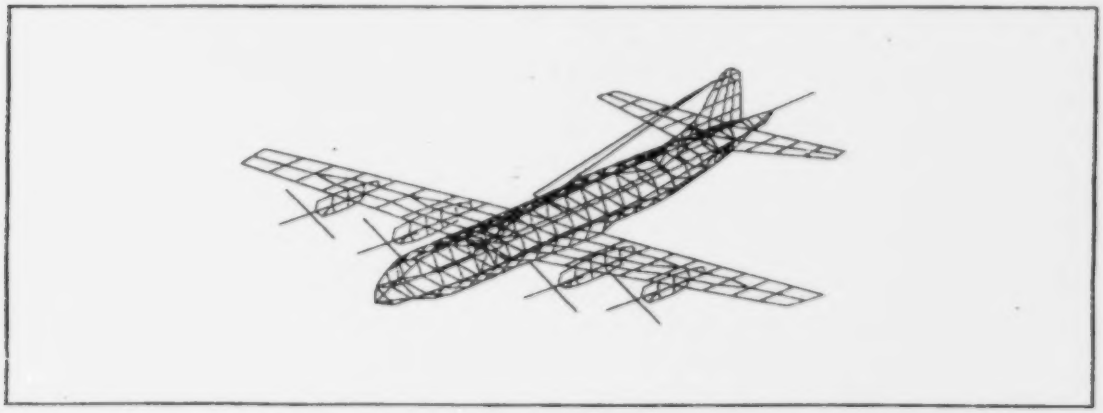

Fig. 2.2 - CP-140/AURORA Model AUR7, 815 Segments

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In preparation for the evaluation of the results, it is instructive to recall how the HF system would be modelled by AAPG [3]. An output power level would be specified for the transmitter over the HF band and assumed to be available at the antenna terminals. In addition, harmonic power levels are assigned. The antenna would require the assignment of a source point and a gain value. Most likely, a dipole value would be chosen for the latter and the standoff insulator feedthrough element would be selected as the source point for the port wire antenna on the CP-140. Corresponding values of receiver antenna gain would be assigned, coupled to an appropriate value of receiver sensitivity.

The pithy question then, from the EMC analysis point of view, would be whether the values of the EMI margin thus produced for VHF antennas at HF frequencies, which are "out-of-band" for VHF, are overestimated or underestimated? How about the values at HF harmonic frequencies which are "in-band" for VHF? In this present analysis, it must be assumed that the wire-grid model values are more representative of actual values until reliable measurement results become available. Also, for both cases, how far off are the AAPG values? These questions have not been addressed heretofore, and the results that follow begin to provide us with some insight into the ramifications for some practical cases.

2.1 Baseline AAPG Model Calculations

An AAPG data set that had been used in previous EMC analysis was obtained and adapted to this study. For efficient execution, the file was reduced to include only the HF and VHF/UHF systems.

The antenna locations selected were atypical of top and bottom antenna locations. Thus the VHF Homer antenna locations on the top and bottom were selected and the VHF antenna on the vertical stabilizer as an example of an extreme location. The locations of these antennas are shown in the AAPG antenna location displays of Figures 2.1.1 and 2.1.2.

The corresponding HF antenna "source-point" locations are shown in the AAPG figure 2.1.3. Since this initial program did not allow a full frequency sweep of the HF system, typical frequencies of 4, 6, 17, and 28 MHz were selected. The analysis of previous research reports [1] and particularly the impedance vs. frequency plots and the associated current distributions will indicate the general rationale for these frequencies to be sampled.

In this particular project, the results can now be examined with regard to the special issues that are relevant for this study.

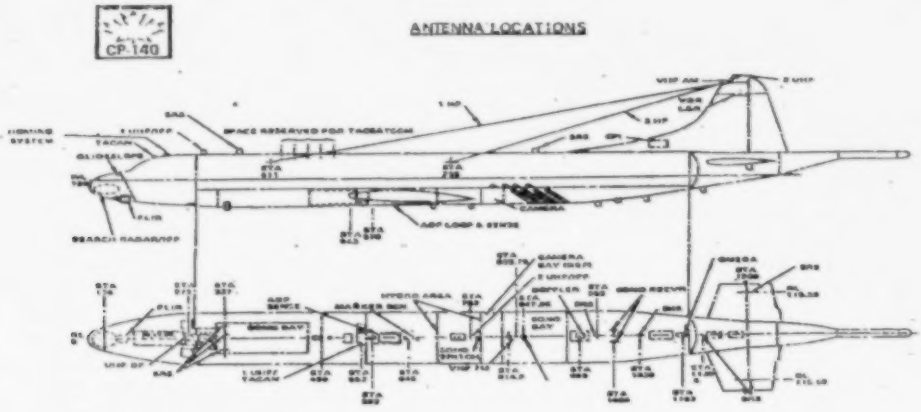

Fig. 2.1.1 - Antenna Locations, Homing System

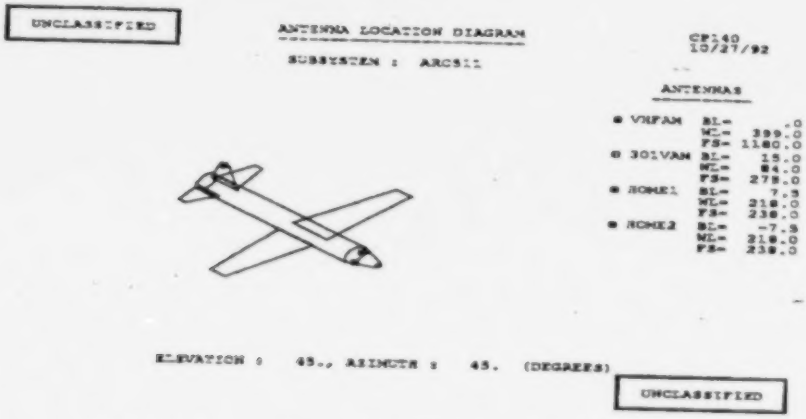

Fig. 2.1.2 - Antenna Locations - AN/ARC-511 System

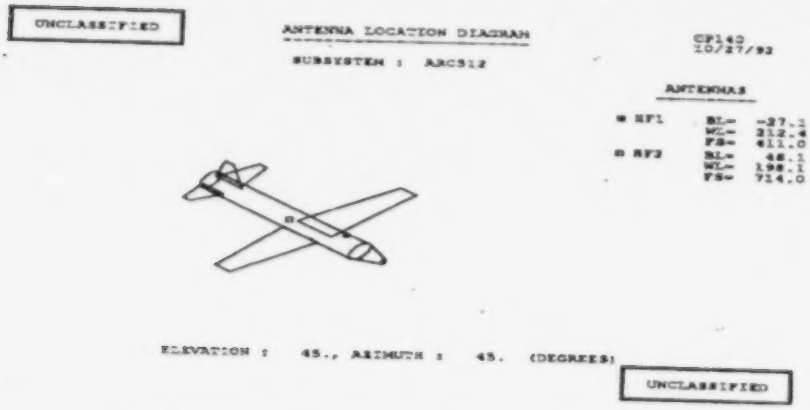

Fig. 2.1.3 - HF Antenna Source Locations

2.1.1 AAPG Baseline Results - HF In-Band Values

The results of the AAPG EMI Margin calculations are presented in the set of figures 2.1.1.1 to 2.1.1.9 below. Figure 2.1.1.1 shows the coupling from the feedpoint of HF1 to the tail-mounted VHF antenna at 4MHz.

Fig. 2.1.1.1 - HF1 to VHFAM Coupling, CP-140, 4MHz.

Note that the nominal dipole gains are used here for both the source and receptor antennas. Note also that the Friis free space propagation loss is computed from the designated source point of the antenna and that it has a negative value.

The results of the coupling calculations to the DF 301VAM antenna are shown in Fig. 2.1.1.2. Note that here there is a creeping wave loss factor evident and a very small value of Friis free space transmission loss, reminding us of the expectation that at some close-in distance, this factor will go to zero. Fig. 2.1.1.3 shows the coupling to the HOME1 antenna on top of the aircraft. Note the very small value of creeping wave loss and a **positive** value of the Friis free space propagation loss! Hereby indeed we are notified by AAPG of the distance/frequency limitations of the formulations within the code.

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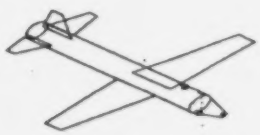
ELECTROMAGNETIC INTERFERENCE MARGIN CALCULATION — CP140 10/24/92

TRANSMITTER: AMC912 (912TX1) RECEIVER: AMC911 (911RX1)

DESCRIPTION	HARMONIC 1 4.000 MHZ	HARMONIC 2 4.000 MHZ
TRANSMITTER POWER	50.0	6.0
XMTR CABLE LOSSES	-.9	-.9
XMTR ANTENNA GAIN	2.1	2.1
TRANSMISSION LOSS	-.2	-.2
SURFACE SHADING	-3.1	-3.1
EDGE SHADING	.0	.0
RCVR ANTENNA GAIN	2.1	2.1
RCVR CABLE LOSSES	-.9	-.9
RCVR SENSITIVITY	-97.6	-97.6
EMI MARGIN	150.5 \< 1	104.3 \< 1
\ FIELD WARNING	---	---



(1.01-10)

TRANSMITTER ANTENNA
@ HF1 EL = -19.32
(MAIN) AZ = -53.81
RECEIVER ANTENNA
@ 101VAM EL = -19.16
(MAIN) AZ = -116.99

ELEVATION = 45. DEG.
AZIMUTH = 45. DEG.

UNCLASSIFIED

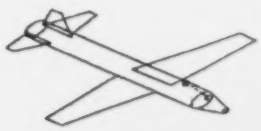
Fig. 2.1.1.2 - HF1 to DF/Homer Coupling, 4MHz, Bottom

UNCLASSIFIED

ELECTROMAGNETIC INTERFERENCE MARGIN CALCULATION — CP140 10/24/93

TRANSMITTER: AMC912 (912TX1) RECEIVER: AMC911 (911RX1)

DESCRIPTION	HARMONIC 1 4.000 MHZ	HARMONIC 2 4.000 MHZ
TRANSMITTER POWER	50.0	6.0
XMTR CABLE LOSSES	-.9	-.9
XMTR ANTENNA GAIN	2.1	2.1
TRANSMISSION LOSS	-.4	-.4
SURFACE SHADING	-3.1	-3.1
EDGE SHADING	.0	.0
RCVR ANTENNA GAIN	2.1	2.1
RCVR CABLE LOSSES	-.9	-.9
RCVR SENSITIVITY	-97.6	-97.6
EMI MARGIN	144.1 \< 1	110.1 \< 1
\ FIELD WARNING	---	---



(1.01-20)

TRANSMITTER ANTENNA
@ HF1 EL = 4.57
(MAIN) AZ = 14.81
RECEIVER ANTENNA
@ HOME1 EL = 19.34
(MAIN) AZ = -170.39

ELEVATION = 45. DEG.
AZIMUTH = 45. DEG.

UNCLASSIFIED

Fig. 2.1.1.3 - HF1 to Homer Antenna Coupling, 4MHz., Top

The corresponding computations and plots for 6 MHz are shown in Figures 2.1.1.4 through 2.1.1.6 respectively. Note that because of the higher frequency, the Friis transmission loss values are all negative.

The computations and plots at 17 MHz are shown in Figures 2.1.1.7 through 2.1.1.9. As before the Friis loss values are negative. These results then pose the main question whether with the use of nominal values for antenna gain and the source points at the antenna feed, the margin values would be representative or at best be on the "safe" side for EMC evaluation purposes. The comparisons of the next section allow us to address this question for the first time.

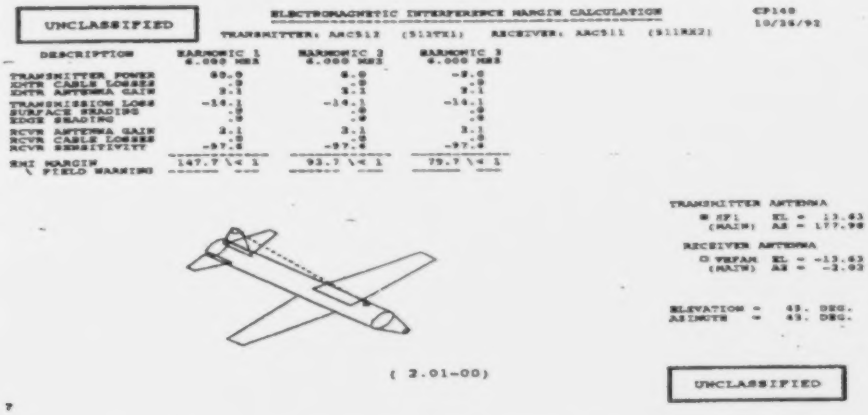

UNCLASSIFIED
ELECTROMAGNETIC INTERFERENCE MARGIN CALCULATION
CP140
10/26/92
TRANSMITTER: AAC511 (511TX1) RECEIVER: AAC511 (511RX2)
DESCRIPTION
HARMONIC 1 4.000 MHz
HARMONIC 2 8.000 MHz
HARMONIC 3 6.000 MHz
TRANSMITTER POWER 40.0 8.0 -8.0
XMTR CABLE LOSSES .0 .0 .0
XMTR ANTENNA GAIN 3.1 3.1 3.1
TRANSMISSION LOSS -34.1 -34.1 -34.1
SURFACE GRADING .0 .0 .0
EDGE GRADING .0 .0 .0
RCVR ANTENNA GAIN 3.1 3.1 3.1
RCVR CABLE LOSSES .0 .0 .0
RCVR SENSITIVITY -97.6 -97.4 -97.4
EMI MARGIN 147.7 \< 1 93.7 \< 1 79.7 \< 1
\ FIELD WARNING
TRANSMITTER ANTENNA
W.HF1 EL = 13.43
(MAIN) AZ = 177.98
RECEIVER ANTENNA
O.VHFAM EL = -13.43
(MAIN) AZ = -2.02
ELEVATION = 45. DEG.
AZIMUTH = 45. DEG.
(2.01-00)
UNCLASSIFIED

Fig. 2.1.1.4 - HF1 to VHFAM Coupling, 6MHz., Tail

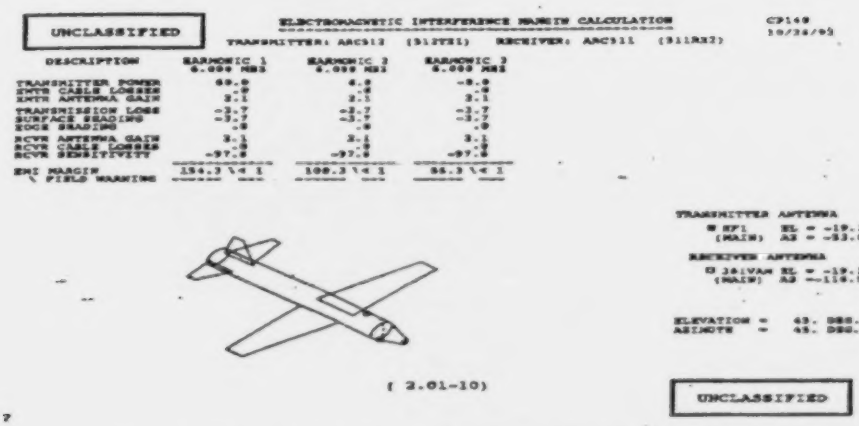

UNCLASSIFIED
ELECTROMAGNETIC INTERFERENCE MARGIN CALCULATION
TRANSMITTER: AHC312 (312TX1) RECEIVER: AHC311 (311RX2)
DESCRIPTION
HARMONIC 1 6.000 MHz
HARMONIC 2 6.000 MHz
HARMONIC 3 6.000 MHz
TRANSMITTER POWER 49.0 6.0 -8.0
XMTR CABLE LOSSES .0 .0 .0
XMTR ANTENNA GAIN 2.1 2.1 2.1
TRANSMISSION LOSS -3.7 -3.7 -3.7
SURFACE SHADING -3.7 -3.7 -3.7
EDGE SHADING .0 .0 .0
RCVR ANTENNA GAIN 2.1 2.1 2.1
RCVR CABLE LOSSES .0 .0 .0
RCVR SENSITIVITY -97.0 -97.0 -97.0
EMI MARGIN 154.3 \< 1 100.3 \< 1 86.3 \< 1
\(FIELD WARNING
TRANSMITTER ANTENNA
HF1 EL = -19.33
(MAIN) AZ = -33.01
RECEIVER ANTENNA
DF1/HOM EL = -19.16
(MAIN) AZ = -116.55
ELEVATION = 43. DEG.
AZIMUTH = 45. DEG.
(2.01-10)
UNCLASSIFIED

Fig. 2.1.1.5 HF1 to DF/Homer Coupling, 6 MHz., Bottom

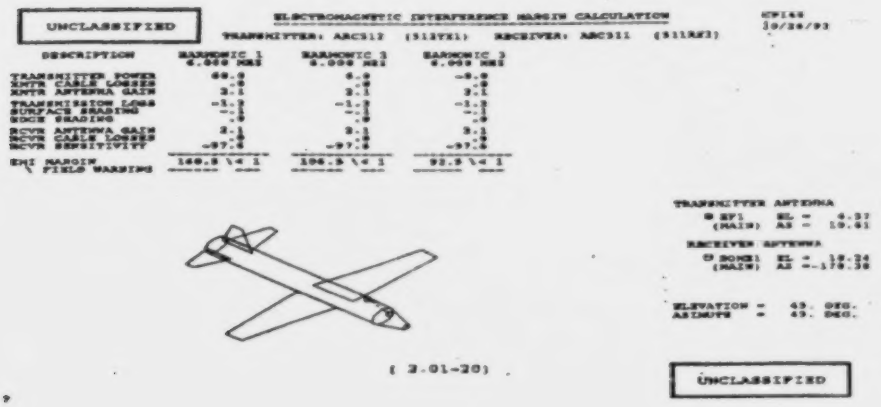

UNCLASSIFIED
ELECTROMAGNETIC INTERFERENCE MARGIN CALCULATION
TRANSMITTER: AHC312 (312TX1) RECEIVER: AHC311 (311RX2)
DESCRIPTION
HARMONIC 1 6.000 MHz
HARMONIC 2 6.000 MHz
HARMONIC 3 6.000 MHz
TRANSMITTER POWER 49.0 6.0 -8.0
XMTR CABLE LOSSES .0 .0 .0
XMTR ANTENNA GAIN 2.1 2.1 2.1
TRANSMISSION LOSS -1.3 -1.3 -1.3
SURFACE SHADING -.1 -.1 -.1
EDGE SHADING .0 .0 .0
RCVR ANTENNA GAIN 2.1 2.1 2.1
RCVR CABLE LOSSES .0 .0 .0
RCVR SENSITIVITY -97.0 -97.0 -97.0
EMI MARGIN 148.8 \< 1 104.8 \< 1 92.8 \< 1
\(FIELD WARNING
TRANSMITTER ANTENNA
HF1 EL = 4.37
(MAIN) AZ = 10.61
RECEIVER ANTENNA
DOME1 EL = 10.34
(MAIN) AZ = -178.38
ELEVATION = 43. DEG.
AZIMUTH = 45. DEG.
(2.01-20)
UNCLASSIFIED

Fig. 2.1.1.6 - HF1 to Homer Coupling, 6 MHz., Top

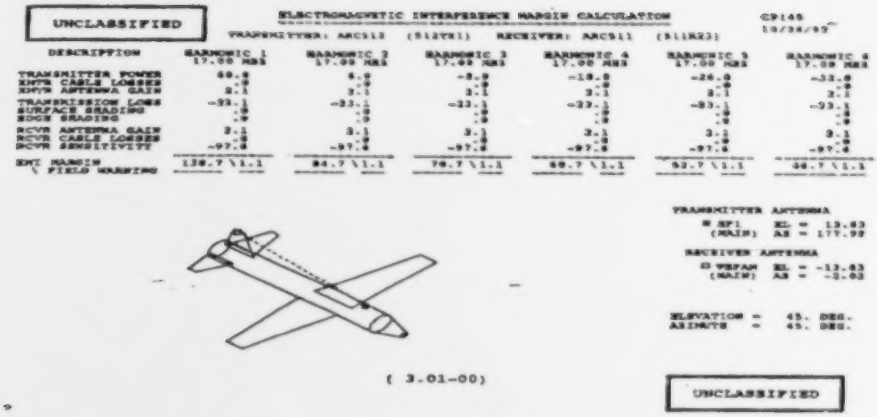

UNCLASSIFIED
ELECTROMAGNETIC INTERFERENCE MARGIN CALCULATION
CP140
10/26/93
TRANSMITTER: AMC512 (512TX1) RECEIVER: AMC511 (511RX2)
DESCRIPTION
HARMONIC 1 17.00 MHz
HARMONIC 2 17.00 MHz
HARMONIC 3 17.00 MHz
HARMONIC 4 17.00 MHz
HARMONIC 5 17.00 MHz
HARMONIC 6 17.00 MHz
TRANSMITTER POWER 40.0 6.0 -8.0 -18.0 -28.0 -38.0
XMTR CABLE LOSSES .9 .9 .9 .9 .9 .9
XMTR ANTENNA GAIN 2.1 2.1 2.1 2.1 2.1 2.1
TRANSMISSION LOSS -33.1 -33.1 -33.1 -33.1 -33.1 -33.1
SURFACE SHADING .8 .8 .8 .8 .8 .8
EDGE SHADING .9 .9 .9 .9 .9 .9
RCVR ANTENNA GAIN 2.1 2.1 2.1 2.1 2.1 2.1
RCVR CABLE LOSSES .9 .9 .9 .9 .9 .9
RCVR SENSITIVITY -97.0 -97.0 -97.0 -97.0 -97.0 -97.0
EMI MARGIN 138.7 \1.1 84.7 \1.1 74.7 \1.1 64.7 \1.1 52.7 \1.1 44.7 \1.1
\ FIELD WARNING
TRANSMITTER ANTENNA
HF1 (MAIN) EL = 13.43 AS = 177.99
RECEIVER ANTENNA
VHFAM (MAIN) EL = -12.43 AS = -2.02
ELEVATION = 45. DEG.
AZIMUTH = 45. DEG.
(3.01-00)
UNCLASSIFIED

Fig. 2.1.1.7 - HF1 to VHFAM Coupling, 17 MHz

UNCLASSIFIED
ELECTROMAGNETIC INTERFERENCE MARGIN CALCULATION
CP140
10/26/93
TRANSMITTER: AMC512 (512TX1) RECEIVER: AMC511 (511RX3)
DESCRIPTION
HARMONIC 1 17.00 MHz
HARMONIC 2 17.00 MHz
HARMONIC 3 17.00 MHz
HARMONIC 4 17.00 MHz
HARMONIC 5 17.00 MHz
HARMONIC 6 17.00 MHz
TRANSMITTER POWER 40.0 6.0 -8.0 -18.0 -28.0 -38.0
XMTR CABLE LOSSES .9 .9 .9 .9 .9 .9
XMTR ANTENNA GAIN 2.1 2.1 2.1 2.1 2.1 2.1
TRANSMISSION LOSS -12.8 -12.8 -12.8 -12.8 -12.8 -12.8
SURFACE SHADING -4.1 -4.1 -4.1 -4.1 -4.1 -4.1
EDGE SHADING .8 .8 .8 .8 .8 .8
RCVR ANTENNA GAIN 2.1 2.1 2.1 2.1 2.1 2.1
RCVR CABLE LOSSES .9 .9 .9 .9 .9 .9
RCVR SENSITIVITY -97.0 -97.0 -97.0 -97.0 -97.0 -97.0
EMI MARGIN 142.8 \< 1 98.8 \< 1 88.8 \< 1 78.8 \< 1 66.8 \< 1 58.8 \< 1
\ FIELD WARNING
TRANSMITTER ANTENNA
HF1 (MAIN) EL = -19.33 AS = -93.01
RECEIVER ANTENNA
301VAM (MAIN) EL = -19.11 AS = -116.53
ELEVATION = 45. DEG.
AZIMUTH = 45. DEG.
(3.01-10)
UNCLASSIFIED

Fig. 2.1.1.8 - HF1 to DF/Homer Coupling, 17 MHz., Bottom

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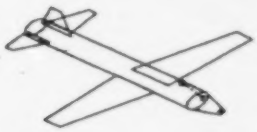
ELECTROMAGNETIC INTERFERENCE MARGIN CALCULATION

CP140
10/24/92

TRANSMITTER: AAC913 (511TR1); RECEIVER: AAC911 (511RM3)

DESCRIPTION	HARMONIC 1 17.00 MHZ	HARMONIC 2 17.00 MHZ	HARMONIC 3 17.00 MHZ	HARMONIC 4 17.00 MHZ	HARMONIC 5 17.00 MHZ	HARMONIC 6 17.00 MHZ
TRANSMITTER POWER	60.0	4.0	-9.0	-19.0	-24.0	-33.0
XMTR CABLE LOSSES	-.8	-.8	-.8	-.8	-.8	-.8
XMTR ANTENNA GAIN	2.1	2.1	2.1	2.1	2.1	2.1
TRANSMISSION LOSS	-19.2	-19.2	-19.2	-19.2	-19.2	-19.2
SURFACE SHADING	-.2	-.2	-.2	-.2	-.2	-.2
EDGE SHADING	-.8	-.8	-.8	-.8	-.8	-.8
RCVR ANTENNA GAIN	2.1	2.1	2.1	2.1	2.1	2.1
RCVR CABLE LOSSES	-.8	-.8	-.8	-.8	-.8	-.8
RCVR SENSITIVITY	-97.4	-97.4	-97.4	-97.4	-97.4	-97.4
EMI MARGIN (- FIELD WARNING)	191.4 \< 1	97.4 \< 1	93.4 \< 1	73.4 \< 1	68.4 \< 1	59.4 \< 1



(3.01-20)

TRANSMITTER ANTENNA
HF1 EL = 6.97
(MAIN) AZ = 19.61

RECEIVER ANTENNA
HOMER EL = -10.24
(MAIN) AZ = -170.38

ELEVATION = 45. DEG.
AZIMUTH = 45. DEG.

UNCLASSIFIED

Fig. 3.1.1.9 - HF1 to Homer Coupling, 17 MHz., Top

2.2 Near-Field Point Values with Available Models

The most direct method of using wire grid models of the CP-140/AURORA is to use them directly to compute the near field values at the locations of the receptor antennas, and then using the 'best' estimate of the "effective height" of the receptor antennas, to compute the voltage induced at the antenna terminals. Assuming a receiver impedance the power could be computed and therefrom the EMI margin computed corresponding to the AAPG calculations. The details of the process are outlined in Appendix B.

The field computation was carried out at the locations of the receptor antennas but at a distance of $\lambda/8$ away from the surface of the wire grid at 100MHz. The coordinates used in AAPG and in the wire-grid model are shown in Table I.

Table I - CP 140 VHF Antenna and Field Point Locations

ANTENNA	AAPG	MODEL 4G	FIELD POINT *
VHF/AM	FS = 1180 = 29.972 m BL = 0 = 0 m WL = 399 = 10.134 m	X = -13.318 m Y = 0 m Z = 6.860 m	X = -13.318 m Y = 0 m Z = 7.479 m
HOMEL (BRISZ)	FS = 238 = 6.045 m BL = 0 = 0 m WL = 218 = 5.537 m	X = 10.609 m Y = 0 m Z = 2.063 m	X = 10.944 m Y = 0 m Z = 2.547 m
301VAM	FS = 279 = 7.086 m BL = 15 = 0.381 m WL = 84 = 2.133 m	X = 9.569 m Y = -0.381 m Z = -1.341 m	X = 9.573 m Y = -0.381 m Z = -0.906 m

REFERENCE POINT : HF1 ANTENNA LOCATION

AAPG	MODEL 4G
FS = 411 = 10.439 m BL = -27.1 = -0.688 m WL = 212.4 = 5.395 m	X = 6.215 m Y = 0.730 m Z = 1.921 m

* Note : the field points are chosen to be approximately λ/8 away from the surface at 100 MHz.

As an initial test, the field was computed at these locations at 4,6,10,17 and 28 MHz. The values are shown in Table II.

Table II - Near Fields at VHF Antenna Locations (Model 4G, Excitation: HF1)

NEAR FIELDS AT VHF ANTENNA LOCATIONS
(MODEL 4GPHX, EX: HF1, WIRES ADDED TO VHF FEED REGIONS, NO RX)

FREQUENCY: 4MHz

ANTENNA	E_x	E_y	E_z	H_x	H_y	H_z
VHF/AM	5.13E-1 4.13°	6.34E-2 15.4°	1.70E-1 -79.0°	4.25E-6 -163.3°	2.74E-4 -90.4°	1.23E-5 -103.7°
HOME1	6.47E-2 73.8°	2.70E-3 107.6°	1.40E-1 82.9°	3.28E-5 -137.4°	1.62E-4 -55.1°	1.82E-5 78.7°
301VAM	5.86E-3 -114.8°	2.09E-2 63.3°	2.76E-2 62.2°	3.35E-4 148.8°	2.51E-4 -24.6°	2.97E-4 151.4°

FREQUENCY: 6 MHz

ANTENNA	E_x	E_y	E_z	H_x	H_y	H_z
VHF/AM	1.62E-1 15.5°	5.36E-3 -94.6°	3.09E-2 14.3°	7.07E-7 76.2°	1.34E-4 -53.5°	1.66E-6 145.9°
HOME1	1.99E-2 88.0°	1.06E-3 135.3°	4.83E-2 99.5°	6.32E-6 -136.4°	4.19E-5 -43.2°	2.65E-6 91.7°
301VAM	1.44E-3 -94.6°	5.06E-3 82.7°	6.56E-3 81.5°	4.67E-5 169.6°	4.67E-5 -5.0°	4.57E-5 171.6°

FREQUENCY: 10 MHz

ANTENNA	E_x	E_y	E_z	H_x	H_y	H_z
VHF/AM	2.43E-1 -12.4°	1.61E-2 -13.4°	8.25E-2 -34.6°	2.62E-7 162.4°	8.87E-5 -36.0°	4.65E-6 -113.8°
HOME1	6.16E-3 -134.0°	1.32E-3 -110.0°	1.13E-2 -130.0°	9.77E-6 54.4°	4.71E-5 92.8°	7.10E-6 -121.0°
301VAM	5.02E-4 3.2°	2.29E-3 -176.5°	3.19E-3 179.2°	1.81E-5 -94.4°	1.42E-5 101.8°	1.51E-5 -87.1°

FREQUENCY: 17 MHz

ANTENNA	E_x	E_y	E_z	H_x	H_y	H_z
VHF/AM	6.66E-2 87.6°	2.32E-2 -177.6°	8.26E-2 -7.9°	9.91E-6 -106.5°	8.06E-5 55.2°	1.73E-5 101.4°
HOME1	5.62E-3 117.1°	1.76E-3 176.3°	2.28E-2 147.3°	5.86E-6 51.0°	9.38E-5 -8.0°	6.34E-6 -171.1°
301VAM	3.16E-4 -45.1°	1.53E-3 103.6°	2.10E-3 97.4°	6.40E-6 -171.3°	1.26E-5 -18.2°	6.93E-6 176.8°

FREQUENCY: 28 MHz

ANTENNA	E_x	E_y	E_z	H_x	H_y	H_z
VHF/AM	1.36E-1 120.3°	1.24E-2 -126.6°	9.55E-2 49.5°	1.23E-5 -158.8°	1.84E-4 102.0°	2.09E-5 134.5°
HOME1	1.57E-2 -70.8°	2.01E-3 -2.1°	4.5E-2 -61.2°	1.50E-5 177.8°	7.63E-5 96.7°	6.78E-6 -9.3°
301VAM	1.42E-3 96.7°	4.95E-3 -90.7°	6.40E-3 -97.9°	8.69E-6 -58.8°	7.90E-6 77.6°	5.69E-6 -52.2°

There is not much relevant information that could be gleaned directly from these values, except their relative magnitudes. However, it is interesting to note that the ratio of the dominant **E** and **H** components is **not** 377 ohms. This points up the need in later refinements of the estimating method to incorporate this consideration as a correction to the method used, which is based on the assumption of free space impedance.

The impedance of HF1 antenna is available from these computations. The resistance of the antenna and the current in the excitation element (for 1 volt excitation) are shown in Table III.

Table III - HF1 Resistance and Feedpoint Current

FREQUENCY (MHz)	R(Ω)	I(mA)
4	13.65	18.46
6	210.72	1.32
10	21.51	7.63
17	34.14	4.24
28	148.68	3.25

These values will be used in the next section to compute the power radiated and equivalenced to the value used in AAPG.

At this point, the equivalent EMI margin values can be computed.

2.2.1 EMI Margin from Near Field Values

Due to the limited resources on the project, a short-cut was taken in reducing the computed comparisons to 4, 6, and 17 MHz. The values computed were based on the assumption of a matched load for the receive antenna. The results are shown in Table IV.

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Table IV
CP-140 Model 4GP
AAPG/NEC-NF COMPARISONS

Frequency	AAPG Trans Power (dBm)	AAPG Rec. (dBm)	AAPG EMI Margin (dB)	INPUT Current (A)	INPUT Resistance (Ω)	Trans. Power* (a) (b) (dBm)	E (V/m)	Voc (V)	RCVR Power (dBm)	EMI Margin* (a) (b)
	BASE									
6	60.0	-97.6	164.1	10.46×10^{-3}	13.65	3.66 2.17	1.40×10^{-5}	5.25×10^{-4}	-31.62	132.32 133.81
6	60.0	-97.6	160.5	1.32×10^{-3}	210.72	-7.36 -8.42	4.83×10^{-6}	1.81×10^{-4}	-30.66	134.10 135.16
17	60.0	-97.6	151.4	4.24×10^{-3}	34.14	-5.13 -5.97	2.28×10^{-5}	8.55×10^{-4}	-37.38	125.35 126.19
	VERAN									
6	60.0	-97.6	151.8	10.46×10^{-3}	13.65	3.66 2.17	3.70×10^{-5}	6.38×10^{-4}	-19.92	134.02 135.51
6	60.0	-97.6	147.7	1.32×10^{-3}	210.72	-7.36 -8.42	3.09×10^{-6}	1.16×10^{-4}	-34.73	130.23 131.29
17	60.0	-97.6	138.7	4.24×10^{-3}	34.14	-5.13 -5.97	8.26×10^{-5}	3.09×10^{-4}	-26.22	136.51 137.35
	VARIOI									
6	60.0	-97.6	158.5	10.46×10^{-3}	13.65	3.66 2.17	2.76×10^{-5}	1.04×10^{-3}	-35.44	118.26 119.75
6	60.0	-97.6	154.3	1.32×10^{-3}	210.72	-7.36 -8.42	6.36×10^{-6}	2.46×10^{-4}	-40.20	116.76 117.82
17	60.0	-97.6	142.6	4.24×10^{-3}	34.14	-5.13 -5.97	2.10×10^{-5}	8.79×10^{-4}	-50.07	104.66 105.50

*Trans. Power: (a) $(1/2)i^2R$, (b) use radiated field computed by IEGLEV

It can be seen that the EMI margin values differ widely. The differences between AAPG and these values are as high as 40 dB, but on the safe side. Thus we have appeared to corroborate the expectation that AAPG values would not be expected to apply within reasonable limits, but if the default gain values are used, the values are positive EMI margin values on the safe side. Thus the alerting feature to problematic coupling is there within AAPG in a crude fashion.

The results of the corresponding calculations with Model AUR7 are shown in Table V. The comparison with AAPG values is similar to that discussed above. It is interesting to note the differences and similarities in near field values between the two models. The nature of such variations should be part of further detailed investigations. For the results obtained using this model, there is one case, VHFAM at 17 MHz, where the near field computations produce a value 4.5 dB above the AAPG one. This would be cancelled if the actual impedance value were used.

It is now of increasing interest to establish how close the EMI margin values would be if they were based on direct coupling computations with NEC. This data is presented in the next section.

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Table V
CP-140 Model AUR7
AAPG/NEC-NF COMPARISONS

Frequency	AAPG Trans Power (dBm)	AAPG Sens. (dBm)	AAPG EMI Margin (dB)	INPUT Current (A)	INPUT Resistance (Ω)	Trans. Power* (a) (dBm)	(b) (dBm)	E (V/m)	Voc (v)	RCVR Power (dBm)	EMI Margin* (a)	(b)
	[illegible]											
4	60.0	-97.6	148.1	0.26 x 10⁻⁶	0.50	0.56	5.48	1.50 x 10⁻⁶	50.4 x 10⁻⁶	-80.61	132.53	131.69
6	60.0	-97.6	140.5	0.16 x 10⁻⁶	163.50	-7.22	-6.07	9.91 x 10⁻⁶	36.5 x 10⁻⁶	-35.3	139.57	138.42
17	60.0	-97.6	151.4	0.41 x 10⁻⁶	50.15	-3.10	-1.98	2.93 x 10⁻⁶	11.0 x 10⁻⁶	-35.3	125.50	124.38
	[illegible]											
4	60.0	-97.6	153.2	25.65 x 10⁻⁶	0.50	0.56	5.48	6.76 x 10⁻⁶	177.7 x 10⁻⁶	-11.88	142.82	141.14
6	60.0	-97.6	147.7	1.63 x 10⁻⁶	163.30	-7.22	-6.07	1.30 x 10⁻⁶	51.7 x 10⁻⁶	-21.76	143.88	141.93
17	60.0	-97.6	138.7	6.10 x 10⁻⁶	50.15	-3.10	-1.98	3.24 x 10⁻⁶	66.0 x 10⁻⁶	-17.53	143.17	142.05
	[illegible]											
4	60.0	-97.6	158.5	25.65 x 10⁻⁶	0.50	0.56	5.48	9.16 x 10⁻⁶	34.35 x 10⁻⁶	-25.88	127.76	126.86
6	60.0	-97.6	150.5	1.63 x 10⁻⁶	163.50	-7.22	-6.07	5.01 x 10⁻⁶	18.79 x 10⁻⁶	-30.56	134.20	133.13
17	60.0	-97.6	142.8	6.10 x 10⁻⁶	50.15	-3.10	-1.98	1.36 x 10⁻⁶	4.88 x 10⁻⁶	-47.35	118.45	117.33

*Trans. Power: (a) (1/2)I²R, (b) use radiated field computed by ISOLAY

2.3 Coupling with VHF Antennas Incorporated into Models

In order to incorporate the receptor antennas into the models, following our EMC Laboratory practice, the feed region at the antenna location was made more dense, in a spider-web pattern and the receptor antenna modelled as a quarter-wave monopole at the specified location. The loading feature of NEC was used to load the antenna terminals with 50 ohms and 1 megohm to simulate typical receive connections.

The modifications to the models are shown in Figures 2.3.1 and 2.3.2 respectively. The received power was computed from the current at the base feed point of the receive antenna and the terminating impedance.

The results are shown in Table VI. For the results obtained with 50 ohm loading, it can be seen that the values for the bottom-mounted homing antenna are within 10 dB of the near-field values. The values for the tail-mounted VHF antenna are within 8 dB of the near-field values. The largest deviation is for the forward top-mounted homing antenna, where at 4 MHz. the difference is 23 dB. However, as before, all the values are below the margins computed by AAPG. For the results obtained with open-circuit loading, while the values of EMI margin are larger than the values of 50 ohm loading but still smaller than the AAPG ones for the two homing antennas, the values for the tail antenna exceed the AAPG ones.

The corresponding values for the AUR7 model are shown in Table VII. Once more there are interesting similarities and differences in the results with the two models. Some commentary on these is provided below.

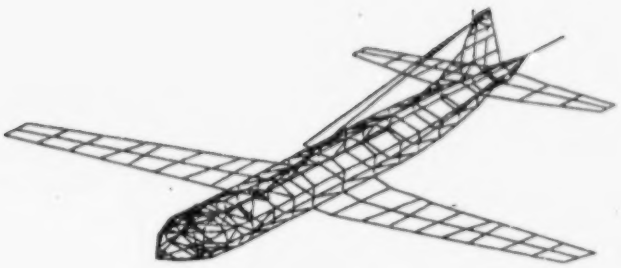

Fig. 2.3.1 Coupling Model 4GP, 559 segments

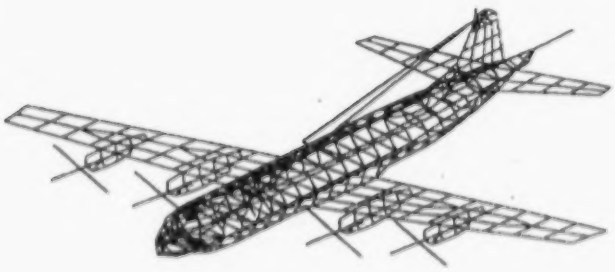

Fig. 2.3.2 Coupling Model AUR7P, 929 segments

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Table VI
CP-140 Model 4GP
AAPG/NEC-LD COMPARISONS
(With VHF Antennas Loaded)

Frequency	AAPG Trans. Power (dBm)	AAPG Recv. (dBm)	AAPG EMI Margin (dB)	Transmitter Power* (a) (dBm)	(b)	Induced Voltage (V) (50Ω)	(open-ckt.)	NCVR Power (dBm) (I)	(II)	EMI Margins** I(a)	I(b)	II(a)	II(b)
4	60.0	-97.6	164.1	3.66	2.17	0.20×10^{-6}	0.138	-43.98	-13.23	109.9	111.4	140.7	142.2
6	60.0	-97.6	160.5	-7.36	-8.42	0.16×10^{-6}	0.47×10^{-6}	-50.00	-22.50	114.9	116.0	142.4	143.4
17	60.0	-97.6	151.4	-5.13	-5.97	0.14×10^{-6}	0.21×10^{-6}	-47.00	-29.50	115.5	116.5	133.2	134.0
	[illegible]												
4	60.0	-97.6	151.2	3.66	2.17	0.14×10^{-6}	0.665	-27.07	0.46	126.0	128.4	154.4	155.9
6	60.0	-97.6	147.7	-7.36	-8.42	0.75×10^{-6}	0.362	-32.50	-0.34	134.7	135.8	156.6	157.7
17	60.0	-97.6	138.7	-5.13	-5.97	0.94×10^{-6}	0.110	-30.10	-14.50	132.5	133.4	148.2	149.0
	[illegible]												
4	60.0	-97.6	150.5	3.66	2.17	0.16×10^{-6}	0.40×10^{-6}	-45.91	-17.96	108.0	109.5	136.0	137.5
6	60.0	-97.6	154.3	-7.36	-8.42	0.56×10^{-6}	0.19×10^{-6}	-55.56	-30.44	109.9	110.9	134.5	135.6
17	60.0	-97.6	142.6	-5.13	-5.97	0.52×10^{-7}	0.62×10^{-6}	-55.60	-40.17	107.0	107.9	122.6	123.4

* Transmitter Power: (a) (1/2)P_t, (b) use radiated field computed by IECLEV
** EMI Margins: (I) 50 Ω loading, (II) open-circuit (1 MΩ) loading

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Table VII
CP-140 Model AUR7
AAPG/NEC-LD COMPARISONS
(With VHF Antennas Loaded)

Frequency	AAPG Trans. Power (dBm)	AAPG Sens. (dBm)	AAPG EMI Margin (dB)	Transmitter Power* (a) (dBm)	(b)	Induced Voltage (V) (50Ω)	(open-ckt.)	RCVR Power (dBm) (I)	(II)	EMI Margins** I(a)	I(b)	II(a)	II(b)
	HFANT												
4	60.0	-97.6	144.1	4.56	5.44	0.26×10^{-3}	0.119	-41.76	-16.91	111.3	110.4	130.5	137.6
6	60.0	-97.6	160.5	-7.22	-6.07	0.19×10^{-3}	0.062	-44.20	-20.17	120.6	119.5	144.6	143.5
17	60.0	-97.6	151.4	-3.10	-1.98	0.28×10^{-4}	0.021	-43.99	-25.57	116.7	115.6	131.1	130.0
	VHFAM												
4	60.0	-97.6	151.2	4.56	5.44	0.28×10^{-4}	0.93	-24.05	3.35	120.9	120.1	136.4	155.5
6	60.0	-97.6	147.7	-7.22	-6.07	0.83×10^{-4}	0.26	-31.62	-7.72	133.2	132.1	157.1	155.9
17	60.0	-97.6	138.7	-3.10	-1.98	0.15×10^{-4}	0.10	-26.46	-10.92	134.2	133.1	149.8	148.7
	VHFSOI												
4	60.0	-97.6	158.5	4.56	5.44	0.17×10^{-3}	0.078	-45.55	-18.18	107.5	106.6	134.8	133.9
6	60.0	-97.6	154.3	-7.22	-6.07	0.12×10^{-3}	0.037	-48.74	-24.65	116.1	114.9	140.2	139.0
17	60.0	-97.6	142.8	-3.10	-1.98	0.94×10^{-4}	0.011	-50.37	-35.19	110.3	109.2	125.5	124.4

*Transmitter Power: (a) $(1/2)I^2R$, (b) use radiated power computed by IBCLAV
**EMI Margins: (I) 50 Ω loading, (II) open-circuit (1MΩ) loading

2.4 Evaluation of the Results

After obtaining the results with different methods and models, one should answer the questions as to which of the methods and models is better or more reliable. The following outlines comparisons between the models and the calculating methods used in this study.

2.4.1 Comparisons between 4GP and AUR7 in AAPG/NEC-NF

The largest differences between the two occur at 6 MHz for all three antenna locations. The results of AUR7 show higher EMI margins than those of 4GP by an amount ranging from 5-18 dB.

For all three frequencies, values obtained with AUR7 are significantly larger than those of 4GP for the tail and bottom homing antennas. The range of differences is between 7-14 dB. For the top homing antenna, results obtained from the two models are close.

As far as the agreement between the AAPG and NEC-NF results is concerned, the more complex model, model AUR7, seems to be better because this model gives results closer to the values predicted by AAPG for the tail and and bottom homing antenna locations.

2.4.2 Comparisons between 4GP and AUR7 in AAPG/NEC-LD

The results between the two are fairly close. The largest differences are in the range of 5-6 dB, which also occur at 6 MHz as in the case of AAPG/NEC-NF. It is seen that the values of AUR7 are slightly larger than those of 4GP.

2.4.3 Comparisons of the results from NEC-NF, NEC-LD, and AAPG

Results obtained from NEC-NF are lower than those from AAPG in most cases. On the other hand, results obtained from NEC-LD with open-circuit loading are larger than the ones from NEC-NF, but the results obtained from NEC-LD with 50 ohm loading are smaller.

Compared to AAPG, the two direct coupling calculation methods predict lower EMI margins except for one case. At the tail antenna location, VHFAM, the open-circuit NEC-LD values are larger than the ones predicted by AAPG. The largest difference is 10 dB occuring at 17 MHz. However, the 50 ohm NEC-LD method still produces values lower than the ones of AAPG at this antenna location.

From the above observations, one may conclude that while the open-circuit NEC-LD method seems to give values closer to the ones predicted by AAPG in most cases, its use sometimes results in values higher than the ones of AAPG. On the other hand, the NEC-NF method gives values significantly lower than the ones predicted by AAPG in most cases. The best choice seems to be the 50 ohm NEC-LD method because its results are closer to but never exceed the ones of AAPG. The more complex model, model AUR7, seems to give better agreement with AAPG than the 4GP model, especially with the NEC-NF method.

3. HF OUT-OF-BAND CALCULATIONS

The use of wire-grid models of large complex structures at VHF frequencies is slowly being explored as computing power and speed increases. The most practical approach for us on this project was to develop a denser version of our CL-600/CHALLENGER model. The larger CP-140 airframe would have resulted in a model with a much higher number of segments and correspondingly longer execution times and larger file handling problems. In addition there are a number of CHALLENGER-based test programs that should be expected to provide corroborating measurement information to support the results of this project at a later date. It should be pointed out that the need for denser CP-140 models should not be neglected as more resources become available. This airframe continues to offer many opportunities for model experimentation and development for use at many other frequencies.

The development of the denser model is a non-trivial task. It is important to preserve the aircraft contours as faithfully as possible and to resolve the many segmentation details at transition areas. Mr. Ariel Ramos carried out this task with extensive use of AUTOCAD software and some use of DIDEC. The AUTOCAD program is especially useful because it allows the use of spline-fitting to the existing set of adjacent node points as the base for interpolation for the creation of new nodes. In the abscence of master-line data sets, this is a practical and efficient approach. This effort resulted in the production of the wire-grid model shown in Figure 3.1. It was targetted for execution at 100MHz and consists of 1915 segments.

This number of segments in a wire-grid model required the re-dimensioning of the EMC Laboratory software for model analysis, model display and the display and analysis of the results. The limited funding on this project could not support this substantial adaptation of the software system. The results that are presented below illustrate the effective use of these modules.

The calculation approach was identical to that used for HF frequencies - near field value determination, and then the incorporation and loading of the receive antenna element. Again three antenna locations were selected: two on top of the fuselage representative of typical VHF antenna locations and one on the bottom of the fuselage. The locations will be illustrated in the AAPG simulations that follow.

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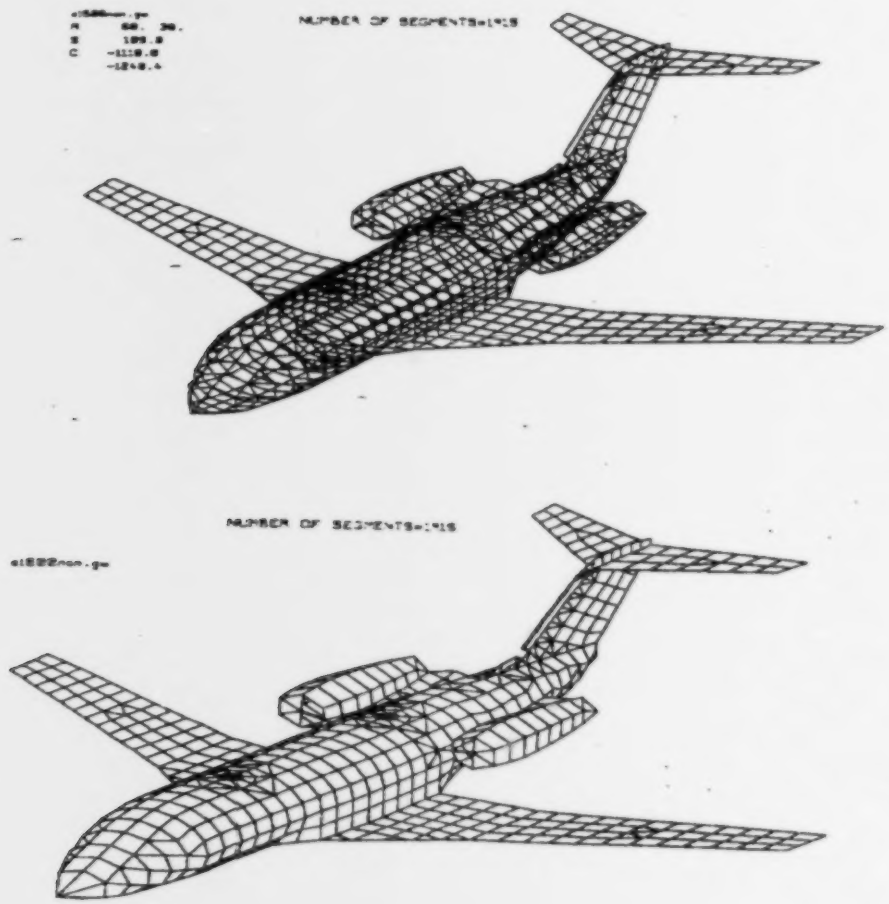

Fig. 3.1 - CL-600/CHALLENGER Wire-Grid Model, 100MHz., 1915 segments

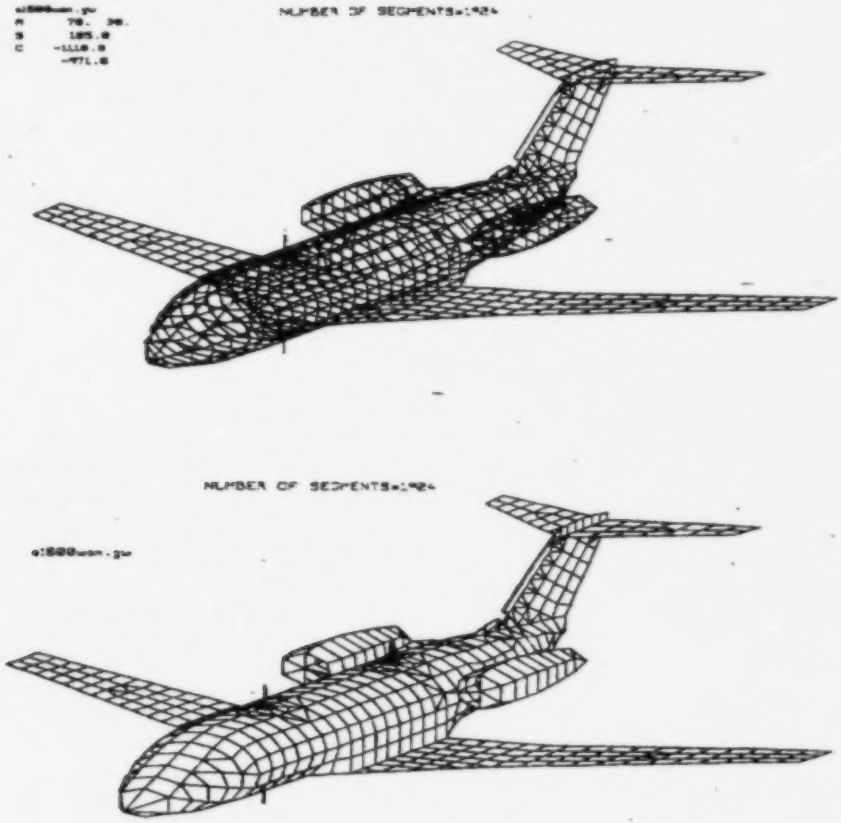

Fig. 3.2 - CL-600/CHALLENGER Direct Coupling Model, 100 MHz, 1924 Segments

3.1 AAPG Model Base-line Calculations - VHF In-Band Values

To establish base-line values, it was decided to execute the AAPG data set for HF and VHF systems at 100MHz., the design frequency for the wire-grid model. The results will have reasonable applicability to the lower portion of the VHF range. The EMI margin displays show the antenna locations and systems involved.

Fig. 3.1.1 shows the EMI Margin values for the HF harmonics coupled to the upper mid-fuselage VHFUHF antenna. Note the HF point source location for HF "notch" antenna. Fig. 3.1.2 shows the EMI margin values for the HF harmonics coupled to the VHF1 antenna on the forward part of the top fuselage. Fig. 3.1.3 shows the EMI margin values for the HF harmonics coupled to the VHF2 antenna on the bottom of the fuselage. It can be seen that this will provide a representative set of physical locations on this airframe.

For the first time, the opportunity to compare these results with NEC wire-grid computations is obtained. How close will the values be?

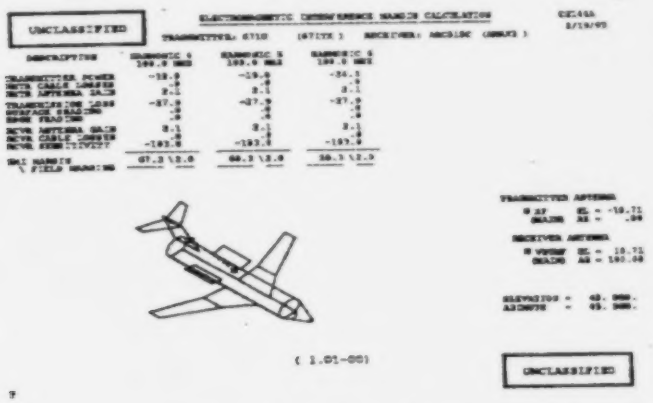

Fig. 3.1.1 - EMI Margin: HF and VHFUHF Mid-fuselage

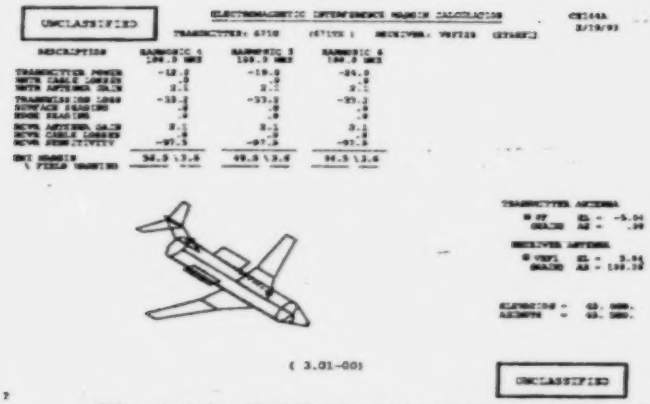

Fig. 3.1.2 - EMI Margin: HF to VHF2 Antenna, FWD Top Fuselage

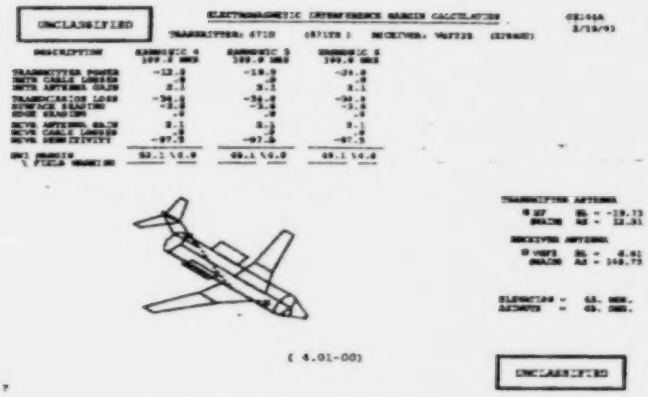

Fig. 3.1.3 - EMI Margin: HF to VHF2 Antenna, Bottom Fuselage

3.2 Near-Field and Direct Coupling Values with VHF CL-600 Model

The execution of the 1915 segment CL-600 model consumed about 3 hrs. of execution time on the EMC Lab Decstation 500. Thus it becomes somewhat unwieldy to do extensive results with models of this size. The model was also modified to incorporate the feed region changes and the attachment of the receptor antennas as shown in Fig. 3.2.

The results of the near-field calculations and the direct coupling calculations are shown in Table VIII. Note now the closer agreement with AAPG results from the near-field calculation method except for the VHF2 antenna location. Most interesting however is the close agreement between AAPG values and the direct coupling calculations with the NEC wire-grid model.

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Table VIII
CL-600/CHALLENGER
AAPG/NEC-NF COMPARISONS AT 100 MHz

Antenna	AAPG Trans Power (dBm)	AAPG Sens. (dBm)	AAPG EMI Margin (dB)	INPUT Current (A)	INPUT Resistance (Ω)	Trans. Power* (a) (b) (dBm)	E (V/m)	Voc (v)	RCVR Power (dBm)	EMI Margin* (a) (b)
VHF1	-12.0	-97.5	56.5	0.93×10^{-3}	70.26	6.94 6.96	9.45×10^{-3}	3.14×10^{-6}	-25.84	55.52 55.50
VHF2	-12.0	-97.5	52.1	0.83×10^{-3}	70.26	6.94 6.96	1.08×10^{-2}	4.09×10^{-6}	-43.87	36.69 36.67
VHONF	-12.0	-103.0	67.3	0.93×10^{-3}	70.26	6.94 6.96	1.96×10^{-2}	7.35×10^{-6}	-10.69	67.37 67.35

*Transmitter Power: (a) $(1/2)I^2R$, (b) use radiated field computed by IEXLEV

Table XI
CL-600/CHALLENGER
AAPG/NEC-LD COMPARISONS AT 100 MHz
(With VHF Antennas Loaded)

Antenna	AAPG Trans. Power (dBm)	AAPG Sens. (dBm)	AAPG EMI Margin (dB)	Transmitter Power* (a) (b) (dBm)	Induced Voltage (V) (50Ω) (open-ckt.)	RCVR Power (dBm) (I) (II)	EMI Margins** I(a) I(b) II(a) II(b)
VHF1	-12.0	-97.5	56.5	6.94 6.96	2.25×10^{-3} 6.04×10^{-3}	-21.96 -20.40	57.62 57.68 60.16 60.24
VHF2	-12.0	-97.5	52.1	6.94 6.96	3.57×10^{-3} 0.73×10^{-3}	-30.94 -30.75	41.62 41.68 41.91 41.79
VHONF	-12.0	-103.0	67.3	6.94 6.96	5.96×10^{-3} 12.34×10^{-3}	-14.66 -10.19	71.60 71.58 71.87 71.85

*Transmitter Power: (a) $(1/2)I^2R$, (b) use radiated field computed by IEXLEV
**EMI Margins: (I) 50 Ω loading, (II) open-circuit (1MΩ) loading

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3.3 Evaluation of the Results

Comparisons between the results of AAPG and NEC-NF show that the NEC-NF method gives EMI margin values very close to the ones of AAPG except for the VHF2 antenna location. In one case, the VHUHF antenna location, the two results are almost identical! However, for the VHF2 antenna location, the value of AAPG is 15 dB higher. The NEC-LD method, on the other hand, give slightly larger EMI margin values than the AAPG, except for the VHF2 antenna location, where the NEC-LD method predicts values 10 dB lower than the ones of AAPG. Also note that NEC-LD results obtained from 50 loading and open-circuit loading are reasonably close. The largest difference is less than 3 dB. This consistency increases our confidence on the NEC-LD direct coupling calculation method.

The three methods we used for this study, namely, the AAPG, the NEC-NF, and NEC-LD, seem to give reasonably consistent results at this frequency except for the VHF2 antenna location. At the VHF2 location, the EMI margins obtained from NEC-NF and NEC-LD are consistently lower than the one from AAPG. Since the VHF2 antenna is located at the bottom of the fuselage, the mechanism of coupling from the HF notch antenna on the dorsal is expected to be more complicated. It is reasonable to believe that the accuracy of the AAPG prediction based on the GTD theory at this lower portion of VHF band could be reduced.

4. SUMMARY AND RECOMMENDATIONS

The following summarizes this investigation and proposes further studies that would help broaden our knowledge of antenna coupling modelling using wire-grid models.

4.1 Surprising results in terms of fail-safe values

In the HF frequency band, AAPG is surprisingly useful for the prediction of antenna EMI margin. Although the values predicted by AAPG may not be accurate, they are on the safe side and hence can be considered as the worst case values.

Except for the VHF2 antenna location, at the VHF frequency of 100 MHz, results obtained with AAPG are almost identical to the ones with NEC-NF, and are slightly lower than the ones with NEC-LD. Since AAPG produces much higher EMI margins than the NEC-NF and NEC-LD methods for the VHF2 location, the AAPG values are again on the safe side at this frequency.

4.2 Comparisons between NEC-NF and NEC-LD

In the HF band, if the values of AAPG are used as the reference values, then the NEC-LD method seems to be better than the NEC-NF method in terms of accuracy since better agreements are seen between AAPG and NEC-LD. At 100 MHz, however, better agreements are seen between AAPG and NEC-NF. The NEC-LD method tends to give higher values than the ones of AAPG at this VHF frequency.

It is noted that the open-circuit NEC-LD method always produces higher EMI margins compared to the NEC-NF method. On the other hand, the 50 ohm NEC-LD method gives values higher than the ones of NEC-NF at 100 MHz, but lower in the HF band.

4.3 Comparisons between two direct coupling calculation methods

The open-circuit NEC-LD method always gives higher EMI margins than the 50 ohm NEC-LD method. The range of differences can be as high as 28 dB in the HF band, but reduces to less than 3 dB at the VHF frequency of 100 MHz.

4.4 Field mapping investigations

It should be interesting to observe the dependence of near field on the wire-grid of the model. In our NEC-NF calculations, we use the point field value at an antenna location to estimate the magnitude of coupling to the antenna. If this point field value greatly depends on the density of the wire-grid or varies sharply within a small region due to the construction of the grid, one should question the accuracy of this value. To investigate the effects of the variation in wire-grid construction on the near field above the grid, one should be able to map the field on a surface above the grid, in addition to finding a few point field values.

The extension of this work to such systematic near-field contour plotting should be undertaken at the earliest opportunity.

4.5 Antenna characteristics and recommended measurements

Some limited literature has been published on the out-of-band characteristics of aircraft antennas. Some of it has been accumulated at EMP test facilities. It would be most productive to have the DREO/EMP Test Facility used for such a purpose in Canada.

5. ACKNOWLEDGMENT

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At the EMC Laboratory, the results represent the combined efforts of Dr. Christopher Trueman, David Gaudine, Ariel Ramos, Quan C. Luu, Dr. Robert Paknys, Ms. Hong Vu, and Mr. Don Davis. All were ably assisted by our EMC Laboratory secretary, Ms. Pamela Fox.

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7. LIST OF APPENDICES

Appendix A - Contract W7714-2-9646/01-ST Statement of Work

Appendix B - Use of Near-Field Values for Coupling Calculations

Appendix A
Contract W7714-2-9646/01-ST
Statement of Work

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ANNEX "A"

STATEMENT OF WORK

LOW FREQUENCY ANTENNA COUPLING MODELLING

The contractor shall investigate means for overcoming the low frequency limitations of antenna/antenna coupling within AAPG by systematically testing the following approaches:

a. The contractor shall use the HF wire-grid models for the CP-140/Aurora for an investigation of "in-band" coupling calculations:

1. The contactor shall calculate the near-field intensity at VHF antenna locations, estimate effective length of the VHF antenna at HF and then calculate the coupled voltage at VHF antenna terminals. A comparison will be made with EMI margins now calculated in AAPG V.07 for this geometry;

2. The contractor shall add a wire segment to represent the VHF antenna, load it for 50 Ohm and open-circuit conditions and compute the induced voltage at the VHF antenna terminals. A comparison will then be made of the EMI margins calculated with AAPG V.07 and from the near-field approach of para a.1, above;

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3. An evaluation shall be made of the two approaches described above and recommendations made as to which should be used.

b. The contractor shall use the model of the CL-600/CHALLENGER for an investigation of HF "out-of-band" calculations.

1. The CL-600 wire-grid model shall be modified to be of sufficient density for use at lower VHF frequencies. Modifications to the EMC Laboratory software shall be made to cater for the larger segment number limits;

2. The dense CL-600 model shall be used to compute the near-field at upper VHF antenna locations as described under para a.1, above, together with the EMI margin comparisons;

3. A VHF antenna segment shall be added to the dense CL-600 model as described above in para a.1, and the model shall be executed and the results evaluated as noted in para a.2, above;

4. An evaluation shall be made of the two approaches described above and recommendations will be made for their use.

Appendix B
Use of Near Field Values for Coupling Calculations

TRANSMITTED POWER

METHOD a)

$$P_t = \frac{1}{2} I^2 R$$

WHERE I = CURRENT ON THE FEED ELEMENT OF THE TRANSMITTING ANTENNA

R = INPUT RESISTANCE OF THE TRANSMITTING ANTENNA

METHOD b)

USE RADIATED POWER CALCULATED BY ISOLEV.

CALCULATIONS OF POWER COUPLED TO A RECEIVER ANTENNA

1) FROM THE NEAR FIELD E :

$$V_{oc} = E\, h_e$$

WHERE h_e = EFFECTIVELENGTH = $\frac{1}{2}\, l$

l = LENGTH OF THE ANTENNA

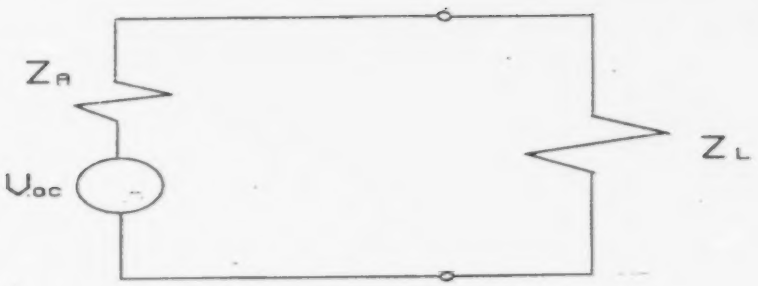
ASSUME $Z_A = Z_L = 50\ \Omega$

$$P_r = \frac{1}{2}\left(\frac{V_{oc}}{Z_A + Z_L}\right)^2 * Z_L$$

$$= \frac{1}{2}\left(\frac{V_{oc}}{100}\right)^2 * 50$$

$$P_r(\text{dBm}) = 10 Log\left(\frac{P_r}{10^{-3}}\right)$$

2) FROM THE INDUCED VOLTAGE



Z_A = ANTENNA IMPEDANCE
Z_L = LOAD IMPEDANCE

I) INDUCED VOLTAGE ACROSS 50 Ω:

$$Z_L = 50\ \Omega$$

$$V_{Z_L} = V$$

$$P_r = \frac{1}{2}\ \frac{V^2}{50}$$

$$P_r(dBm) = 10Log(\frac{P_r}{10^{-3}})$$

II) INDUCED VOLTAGE ACROSS 1 MΩ (OPEN CIRCUIT):

$$V = V_{oc}$$

$$V_{R_L} = \frac{V_{oc}}{2}$$

$$P_x = \frac{1}{2} \frac{V_{R_L}^2}{50}$$

$$P_x(dBm) = 10Log(\frac{P_x}{10^{-3}})$$

CP140-MODEL 4GP

AAPG/NEC-NF COMPARISONS

FREQUENCY : 4 MHz

AAPG
TP : 60
X CL : 0.0
X GAIN : 2.1

TRANS LOSS :2.4
S.S. :-0.1
E.S. :0.0

RCVR GAIN :0.1
R C.L. :0.0
RCVR SENS.:-97.6
EMI MARGIN: 164.1

NEC/NF

1- TRANSMITTED POWER EQUIV.

$$a\text{- POWER INTO ANTENNA} = \frac{1}{2} I^2 * R_r = \frac{1}{2} (18.46 * 10^{-3})^2 * 13.65$$

$$= 2.33 * 10^{-3}$$

$$dBm = 10 Log\left(\frac{2.33 * 10^{-3}}{10^{-3}}\right) = 3.66$$

b- POWER COMPUTED BY ISOLEV = 0.00165 W

$$dBm = 10 Log\left(\frac{0.165 * 10^{-2}}{10^{-3}}\right) = 2.17$$

2- POWER AT RECEIVER ANTENNA

$$V_{oc} = E\, h_e = E\,(\frac{1}{2}\,L)$$

$$-1.40*10^{-1}*(0.375) = 0.0525$$

Assume $Z_A = R_r = 50\ \Omega$

$$P_r = \frac{1}{2}(\frac{V_{oc}}{Z_A+R_r})^2 R_r$$

$$= \frac{1}{2}(\frac{5.25*10^{-2}}{50+50})^2*50 = 6.89*10^{-6}\ W$$

$$P_R(dBm) = 10\log(\frac{P_r}{10^{-3}}) = 10\log(\frac{6.89*10^{-6}}{10^{-3}}) = -21.62$$

MARGIN OVER RECEIVER SENSITIVITY = -21.62 + 97.6 = 75.98

POWER LEVEL EQUALIZATION :

a) 60 -3.36 + 75.98 = 132.32

b) 60 - 2.17 + 75.98 = 133.81

CP140-MODEL 4GP

AAPG/NEC-LD COMPARISONS

FREQUENCY : 4 MHz

AAPG

1- TRANSMITTED POWER = 60 dBm

2- RECEIVER SENSITIVITY = -97.6 dBm

3- EMI MARGIN = 164.1 dB

NEC/LD

1- TRANSMITTED POWER (AS IN NEC/NF)

a- P_T = 3.66 dBm
b- P_T = 2.17 dBm

2- POWER AT RECEIVER ANTENNA

I. 50 Ω LOADING

$$P_r = \frac{1}{2}\frac{V^2}{50} = \frac{1}{2}\frac{(0.20*10^{-2})^2}{50} = 4.0*10^{-8}\ W$$

$$P_R\ (dBm) = 10\ Log\left(\frac{4.0*10^{-8}}{10^{-3}}\right) = -43.98$$

MARGIN OVER RECEIV.SENSITIVITY = -43.98 + 97.6 = 53.62

POWER LEVEL EQUALIZATION:

a- 60 - 3.66 + 53.62 = 109.96 dBm
b- 60 - 2.17 + 53.62 = 111.45 dBm

II. OPEN CIRCUIT (1 MΩ LOADING)

$$P_L = \frac{1}{2}\ \frac{(V_{oc}/2)^2}{50} = \frac{1}{2}\ \frac{(0.138/2)^2}{50} = 4.76*10^{-5}$$

$$P_R\ (dBm) = 10\ Log(\frac{4.76*10^{-5}}{10^{-3}}) = -13.22$$

MARGIN OVER RECEIV. SENSITIVITY = -13.22 + 97.6 = 84.38

POWER LEVEL EQUALIZATION:

a- 60 - 3.66 + 84.38 = 140.72 dBm

b- 60 - 2.17 + 84.38 = 142.21 dBm

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This report summarizes the wire-grid modelling methodology and results which were applied to determine IN-BAND and OUT-OF-BAND coupling values for the CP-140/AURORA and the CL-600 aircraft for typical avionic systems. These results are compared to similar values obtained with the AAPG Computer Code.

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TITLE:(U) LOW FREQUENCY ANTENNA COUPLING MODELLING

PERSONAL AUTHOR: Kubina, S.J.; Trueman, C.W.
CORPORATE AUTHOR: Concordia Univ, Montreal QUE (CAN) EMC Lab;Defence Research Establishment Ottawa, Ottawa ONT (CAN)

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